A Beam Test Facility for High Current Photoinjector and its Key Technologies Development at IHEP

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Outline

- PAPS introduction
- A Beam Test Facility for High Current Photoinjector
- Related Key Technologies Development
- Future plan
- Summary and Outlook

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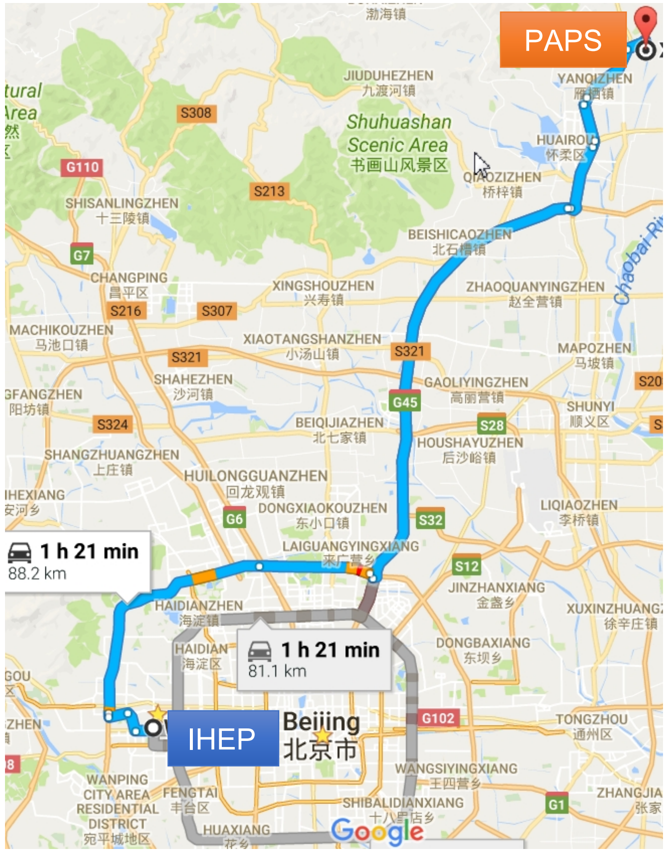
PAPS Introduction

Platform of **A**dvanced **P**hoton **S**ource Technology R&D,
Huairou Science Park, Huairou, Beijing

HEPS



Construction: 2017.5 – 2020.6
Ground Breaking: May 31, 2017

PAPS Introduction

Cryogenic system

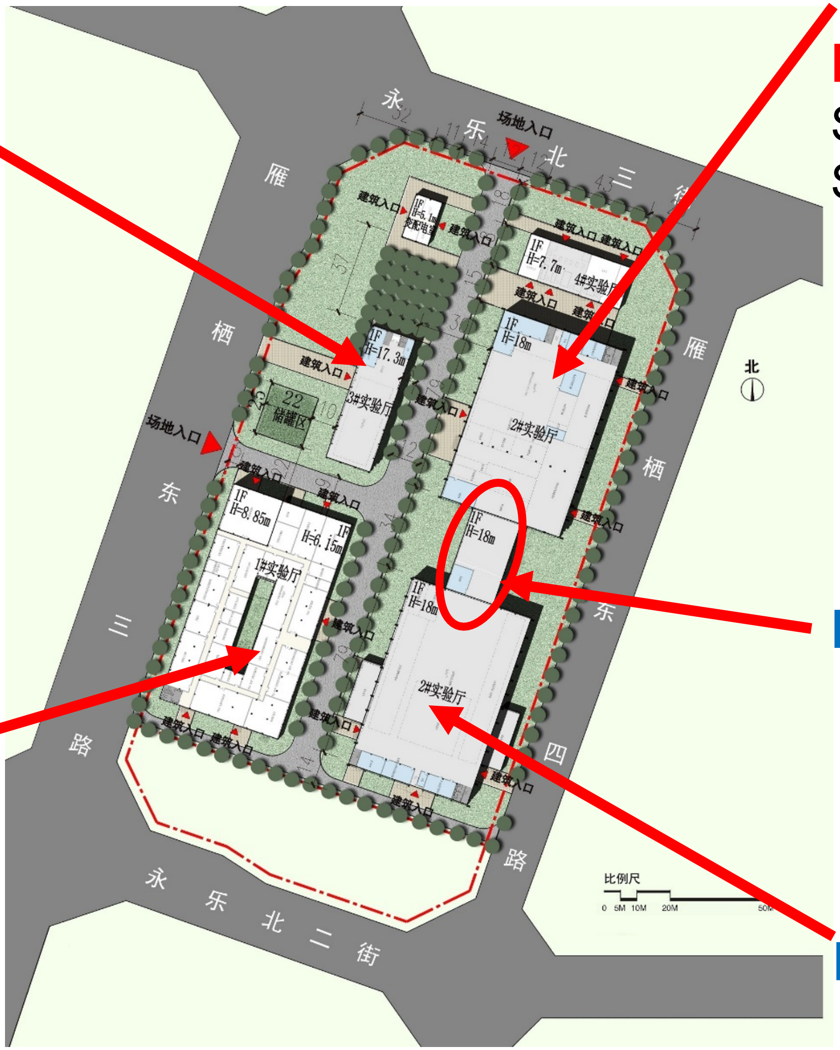
2.5kW@4.5K/300W@2K

800L/h liquidation

- 100W for 3 vertical test stands
- 100W for 2 horizontal module test stands
- 100W for beam test system

X-ray system

- Advanced X-ray related technologies R&D



4500 m^2 SRF lab

Mission: World-leading SRF Lab for future Superconducting Accelerator Projects and SRF Frontier R&D

- Three vertical test stands each with four cavities
- Coupler conditioning stands for eight couplers
- 30 m-long clean room
- 36 m-long module assembly zone
- Two horizontal module test stands (12m module)

Beam test system

- Beam test based on superconducting module
- High power conditioning (High efficiency klystron)
- High current photoinjector R&D

Magnet system

- Precision machining for HEPS magnets

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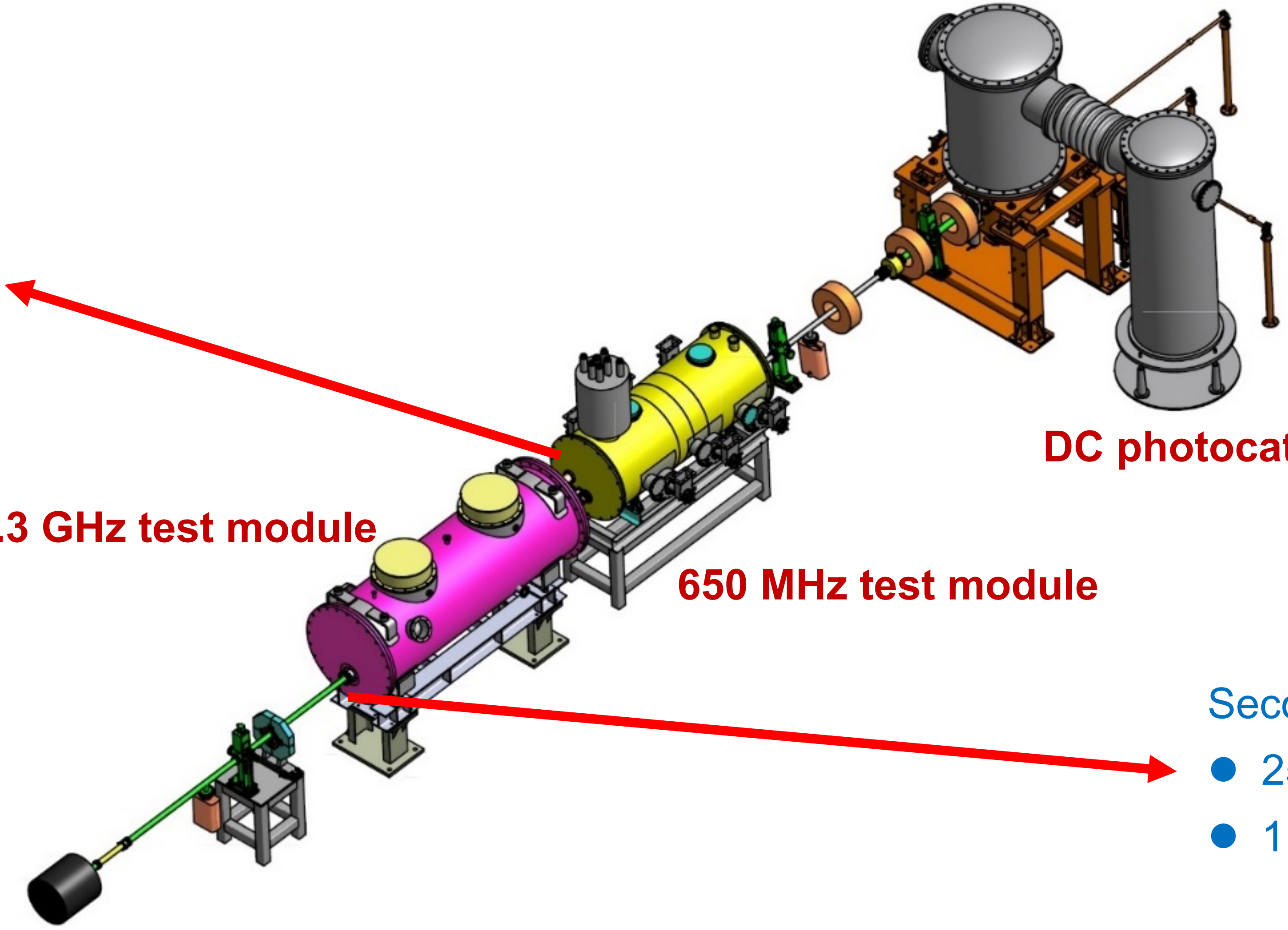
PAPS Beam Test System

First stage:

- 10 ~ 15 MeV
- 1 ~ 10 mA



Second stage:

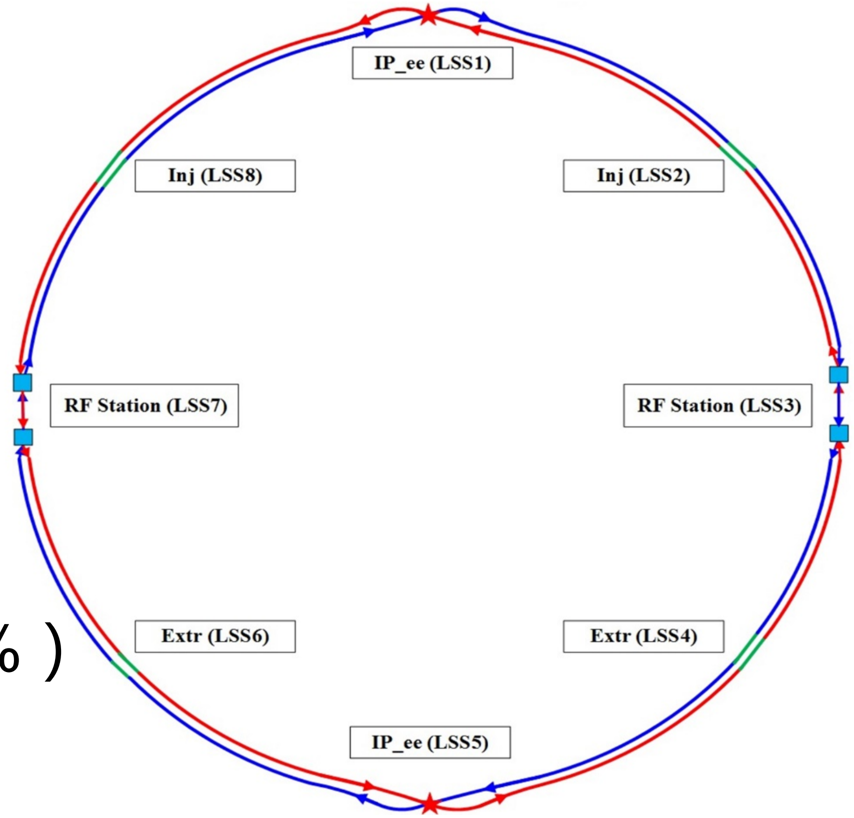
- 25 ~ 30 MeV
- 1 ~ 10 mA

PAPS Beam Test System

Why is 650MHz SRF？

- The R&D of CEPC (Circular Electron Positron Collider)
- Circumference: 100 km
- Ring type: Double Ring (*baseline*)
- SRF System: 650MHz in the Main Ring of CEPC

Layout of CEPC Double Ring



Several key technologies R&D already started

- 650MHz High-Q SRF Cavity
- High power （300kW CW）650MHz Input Coupler
- High power 650MHz Klystron（800kW, efficiency≥75%）
- 650MHz Cryomodule (650 MHz 6 x 2-cell Cavities)
- 1.6MW PSM Power Supply for Klystron

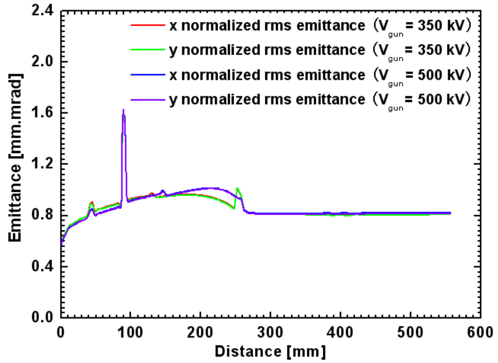
PAPS Beam Test System

Preliminary beam dynamics study

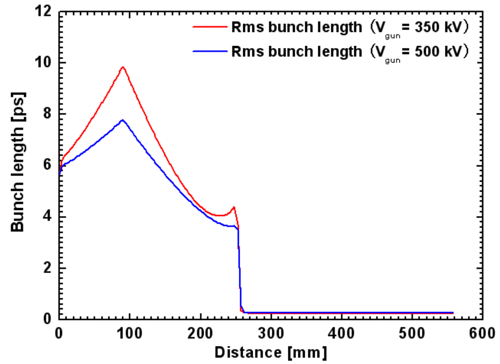
- From gun to exit of 650MHz cryomodule
- To be continued……

Input parameters of simulation

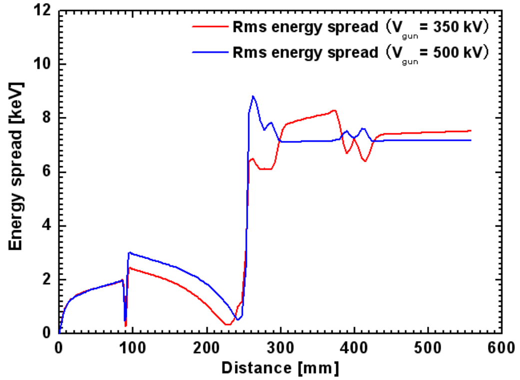
Parameter	Value
DC-gun voltage	350 kV / 500 kV
Beam current	10mA
Bunch repetition frequency	650MHz
Bunch charge	15.4pC
Beam transverse distribution	round and uniform
Beam longitudinal distribution	beer can with 18 ps flat top and 2ps rise/fall time
NC buncher voltage	82.8 kV/ 111.6kV
Gradient for SC cavity	18MV/m



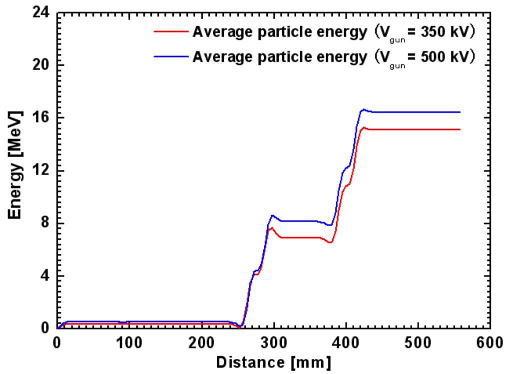
Emittance



Bunch length



Energy spread



Energy

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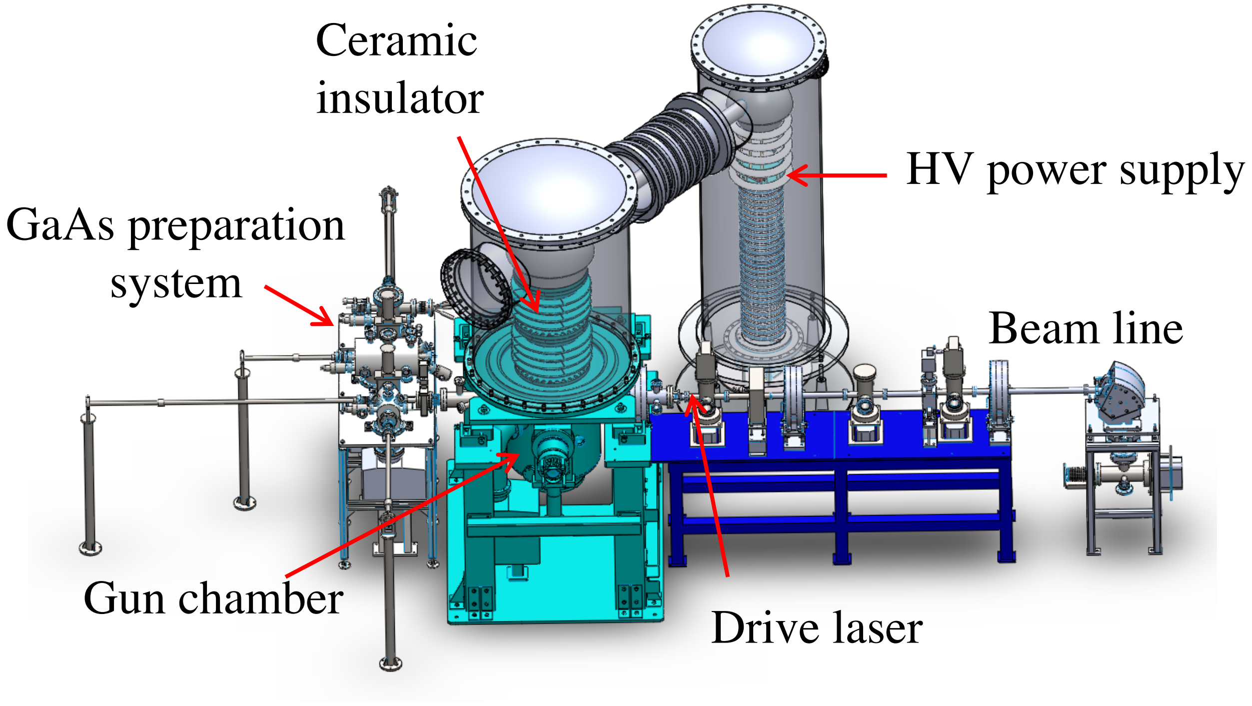
Related Key Technologies Development (1)

A photocathode DC-Gun R&D

- Design and parameters



Layout of Photocathode DC-Gun

Parameter	Value
HV	350 ~ 500 kV
Cathode	GaAs:Cs
QE	5-7%(initial),1%
Driven laser	2.3W， 530nm
Repetition rate	100MHz, 1.3GHz*
Nor. emittance	(1~2)mm.mrad
Bunch length	20ps
Beam current	(1~10) mA

*Two operation modes:

1). 100MHz-7.7mA-77pC, 2)1300MHz-10mA-7.7pC

Related Key Technologies Development (1)

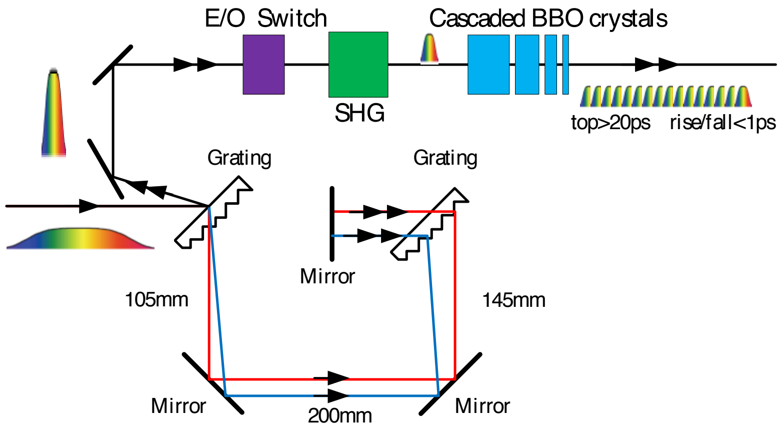
A photocathode DC-Gun R&D

- Construction: Laser system

1. Two laser oscillators are working at 1.3GHz and 100MHz respectively
2. 100MHz and 1.3GHz oscillators are integrated into one laser system with a 2x2 fiber coupler
3. The green laser output power after SHG crystal is more than 5W
4. A set of four a-BBO crystals is used as longitudinal pulse shaper stacking an input pulse to >20ps

Parameters	1st mode	2nd mode
Electron bunch charge	77pC	7.7pC
Pulse energy at cathode	18nJ	1.8nJ
Pulse repetition rate	100MHz	1.3GHz
Power at cathode	1.8W	2.3W
Pulse length (flattop)	20-30ps	20-30ps

Requirements for two operation modes



Laser pulse modification and shaping

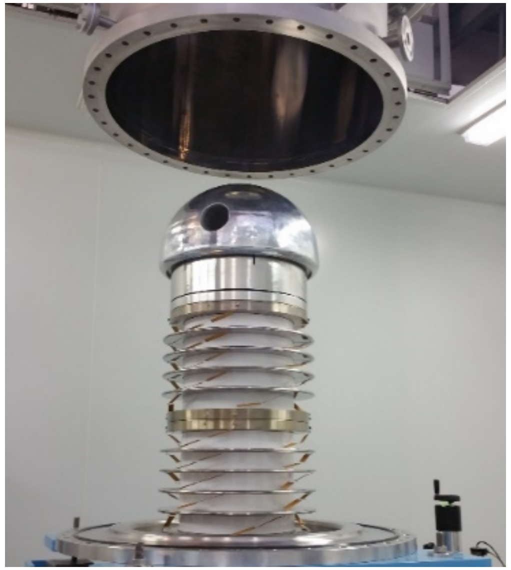
Laser system for photocathode

Related Key Technologies Development (1)

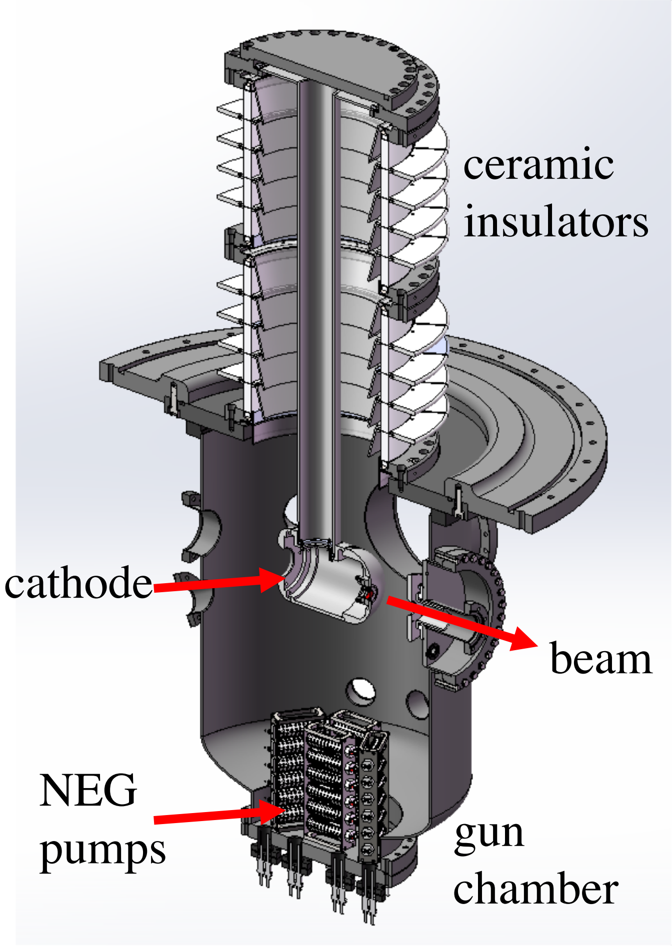
A photocathode DC-Gun R&D

- Construction: ceramics, gun, power supply, beam line……

1. Construction of each component is done
2. Vacuum in the gun achieves 6×10^{-10}Pa
3. Pressurized insulating gas: SF6





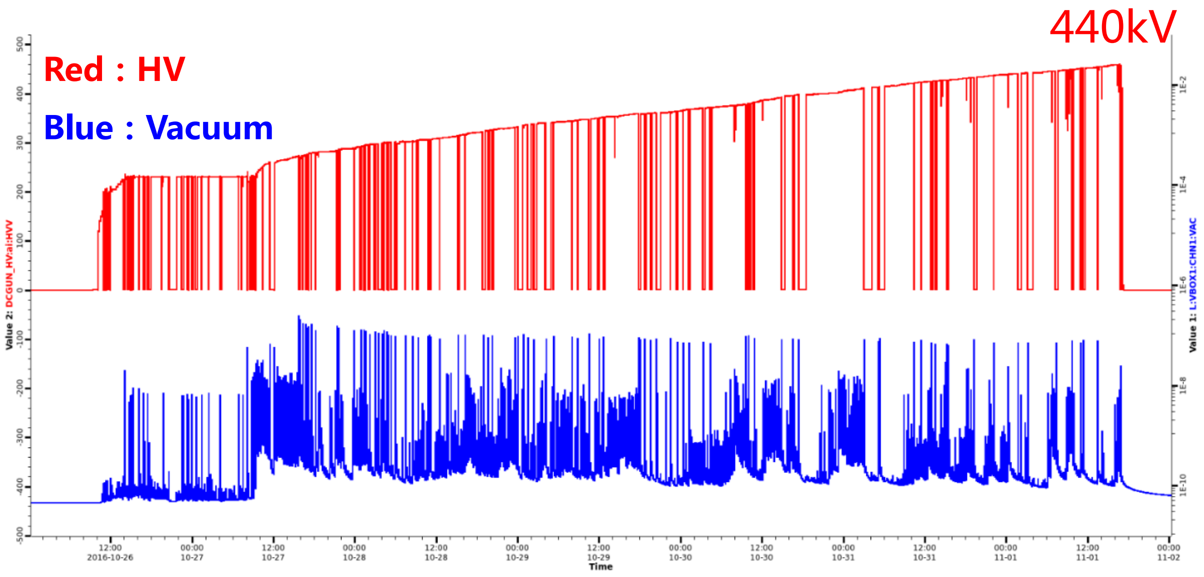


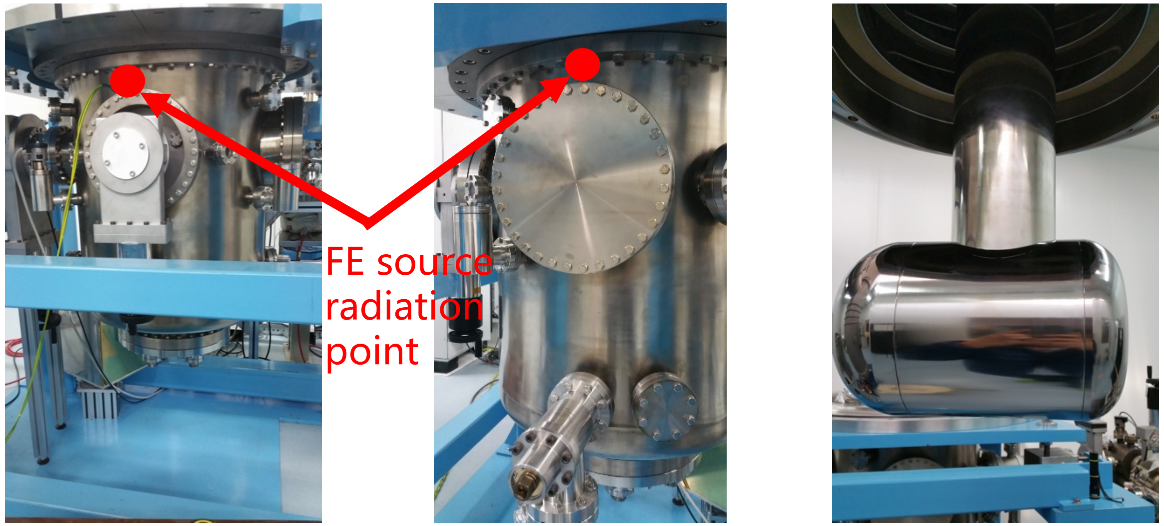
Related Key Technologies Development (1)

A photocathode DC-Gun R&D

- High voltage conditioning

1. The pressure of SF6 in the pressurized tank: 2.5atm
2. The vacuum interlock level is 4×10^{-6}Pa
3. After around 140 hours conditioning, HV reached up to 440kV that means a HV between cathode and anode is around 431kV (5000MΩ/5100MΩ)
4. Then a huge radiation dose caused by field emission was found at one point of gun chamber. There is still a big dose even though reduce the HV to 250kV.
5. Open the gun chamber and repolish the cathode to remove FE source, then recover the vacuum
6. Re-conditioning up to 370kV (HV between cathode and anode is 362kV) without obvious dose
7. Next, beam operation @350kV



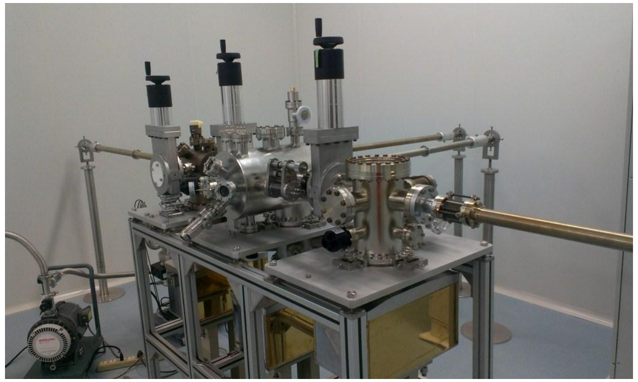


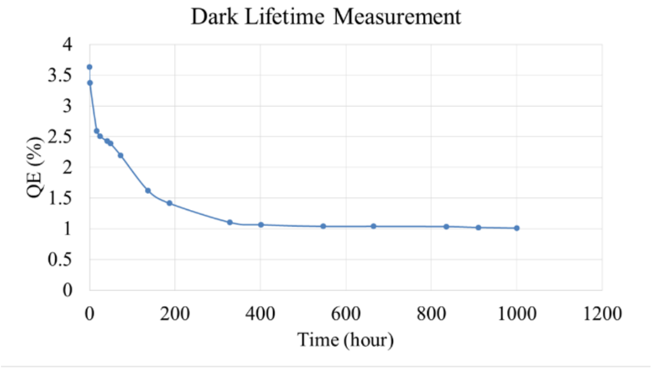
Related Key Technologies Development (1)

A photocathode DC-Gun R&D

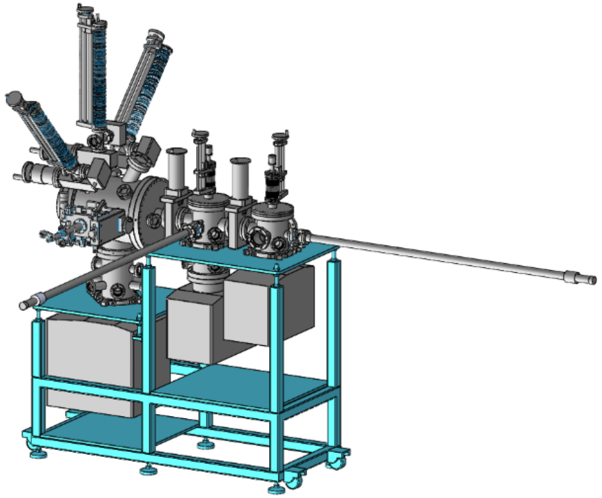
- Photocathode development

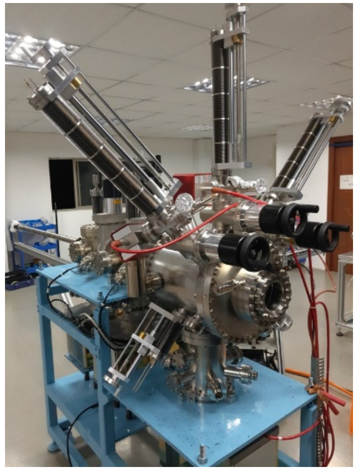
1. A GaAs photocathode system was built up at first
2. Obtained a QE of ~10% after Cs/O activation
3. Dark lifetime can keep 1000hr with QE≥1%
4. In recent, a K_2CsSb photocathode system was set up, growth experiment just started





GaAs photocathode system





K_2CsSb photocathode system

Mo substrate

Related Key Technologies Development (2)

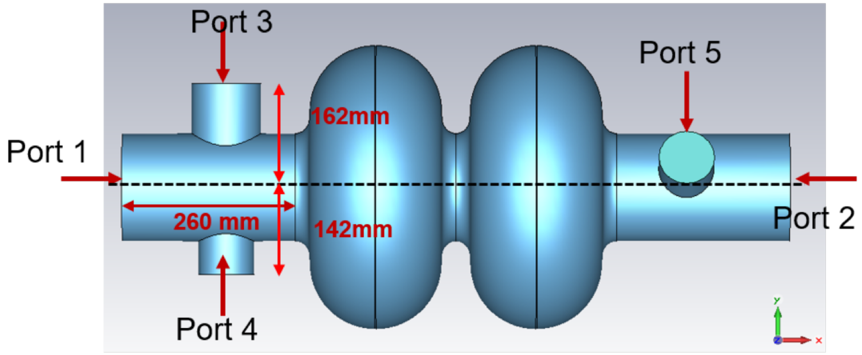
650MHz SRF cavity and Cryomodule

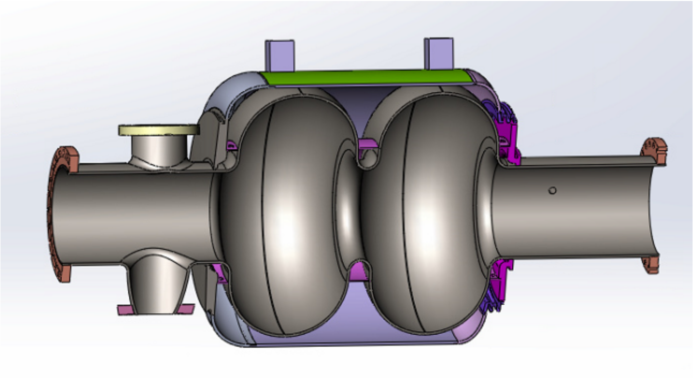
- 650MHz SRF cavity design

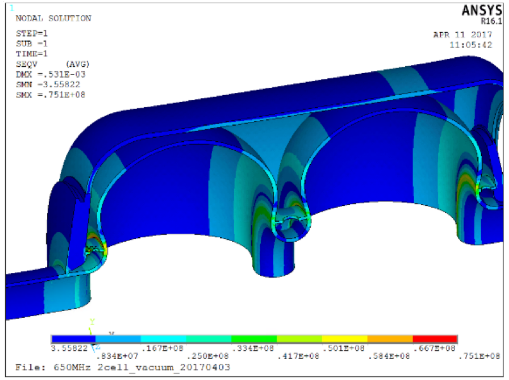
Parameters	Value
R/Q (Ω)	213
G (Ω)	284
Ep/*Eacc*	2.4
Bp/*Eacc* [mT/(MV/m)]	4.2

	***P* (W) (*U* = 1 J)**	***Qe***
Port 1	0.001867	2.19E12
Port 2	0.001352	3.02E12
Port 3	0.005441	7.51E11
Port 4	0.003435	1.19E12
Port 5	0.003320	1.23E12

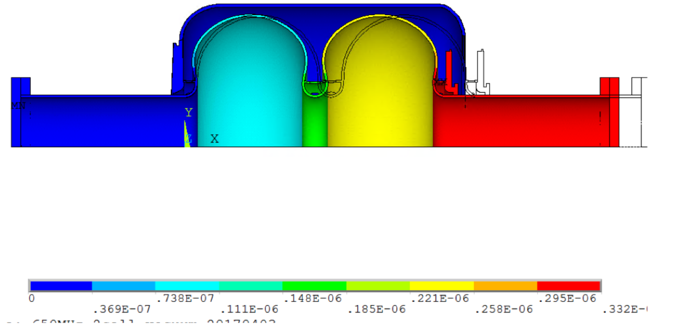
Qe (all ports) : 2.65E+11. If *Q0* = 4E10 , then *Q0* (measured) decrease to 3.48E10.







df/dp and stress

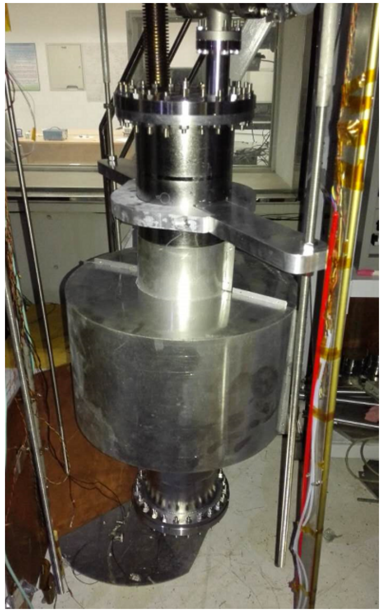


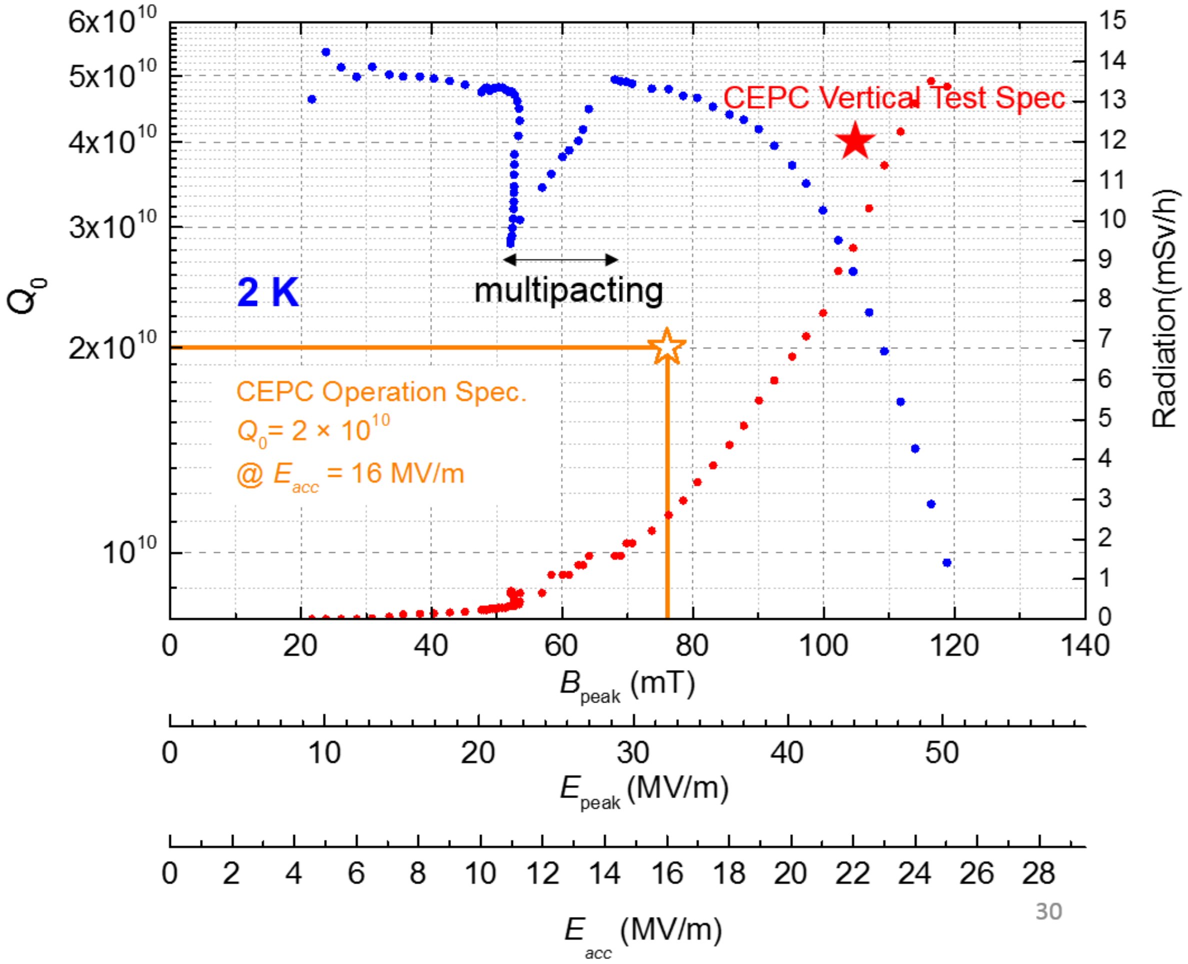
LFD

Related Key Technologies Development (2)

650MHz SRF cavity and Cryomodule

- 650 MHz Single Cell Cavity Test before N-doping



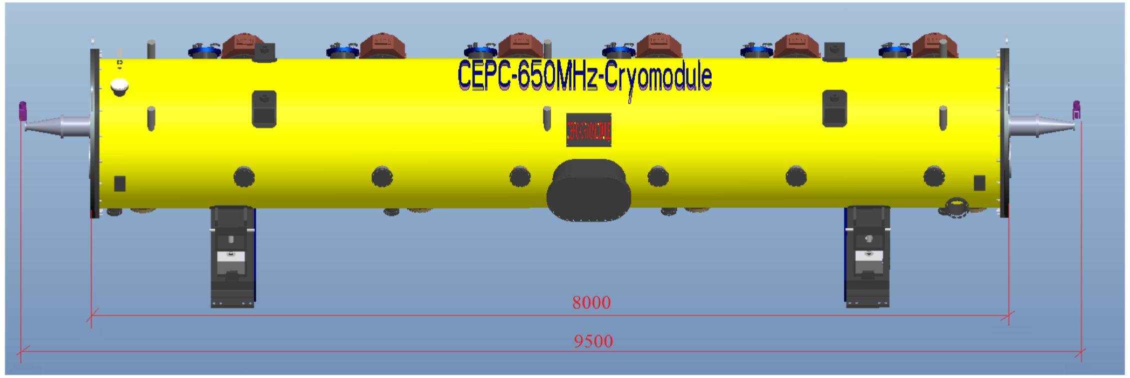


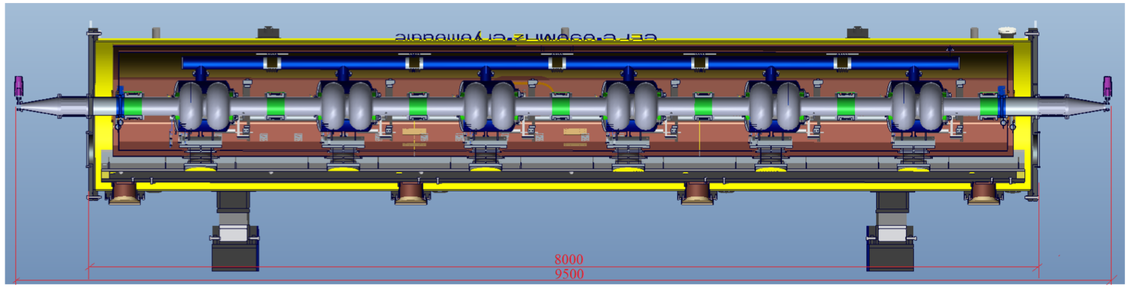
- Fine grain, BCP + 120 C bake 48 h
- $Q_0=4\times10^{10}$ @ Eacc=19.4MV/m
- Next step: cavity N-infusion; N-doping + EP

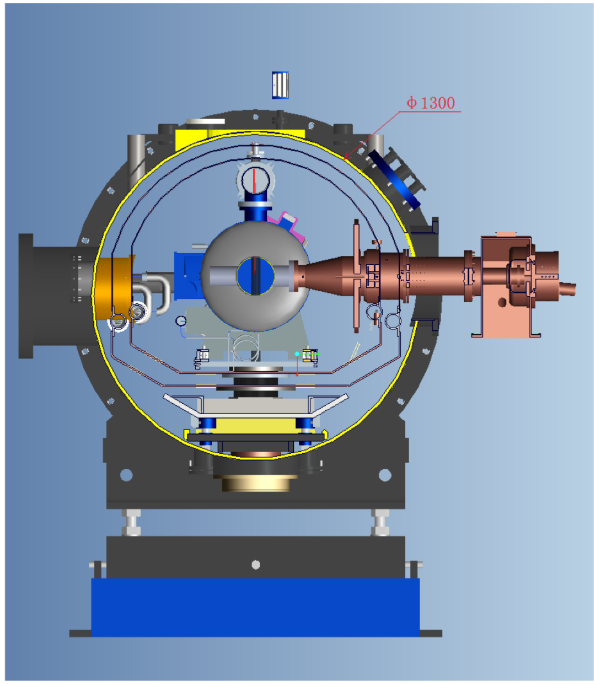
Related Key Technologies Development (2)

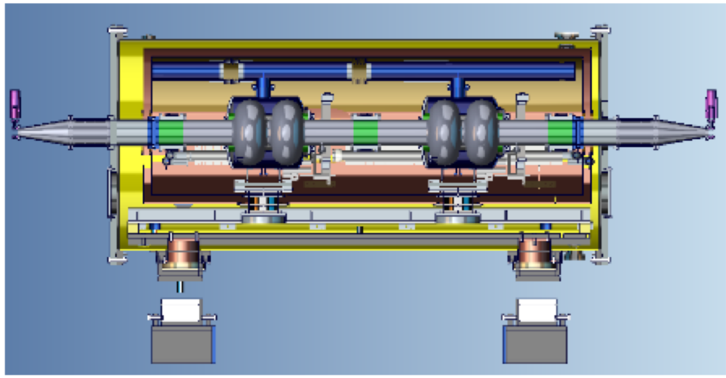
650MHz SRF cavity and Cryomodule

- CEPC full scale Prototype Cryomodule design and small Test Cryomodule for PAPS









PAPS small Test Cryomodule with 650MHz 2 x 2-cell cavities

CEPC full scale prototype cryomodule with 650 MHz 6 x 2-cell cavities

Related Key Technologies Development (3)

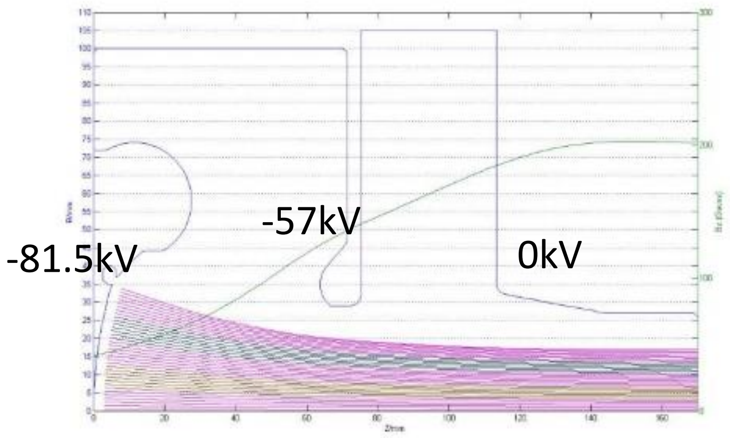
650MHz High Efficiency Klystron (CW 800kW and efficiency≥75%)

- R&D plan
  - 2017-2019 (Prototype 1)
    - Five fundamental cavities and One 2^{nd} harmonic cavity
    - Design is already done and soon the fabrication will be started
    - Plan to finish assembling before December 2018
    - Installed on PAPS (beam test system) before June 2019
    - 600kW with 65% efficiency operation at PAPS
  - 2019-2021 (Prototype 2)
    - First option: Five fundamental cavities, One 2^{nd} harmonic cavity and One 3rd harmonic cavity
    - Second option: 8/9 cavities by using BAC menthod or other methods
    - Finally, achieve 800kW output with efficiency ≥ 75%

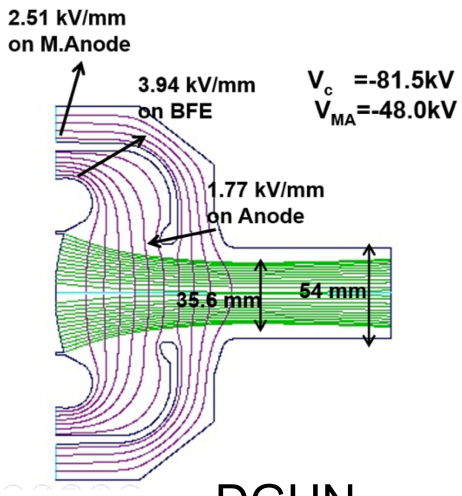
Related Key Technologies Development (3)

650MHz High Efficiency Klystron (CW 800kW and efficiency≥75%)

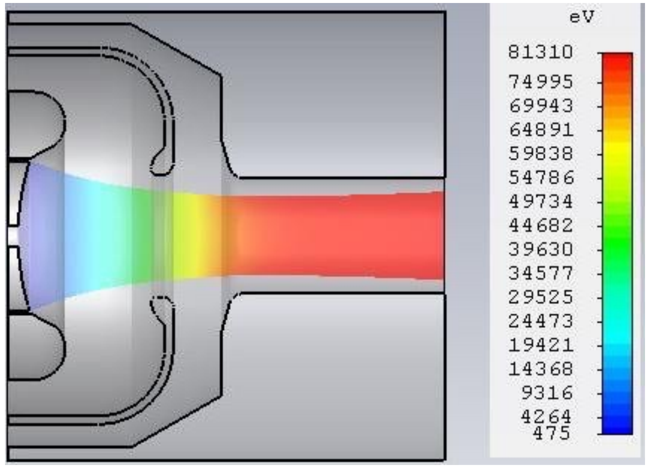
- Prototype 1: Electron gun simulation



EGUN



DGUN



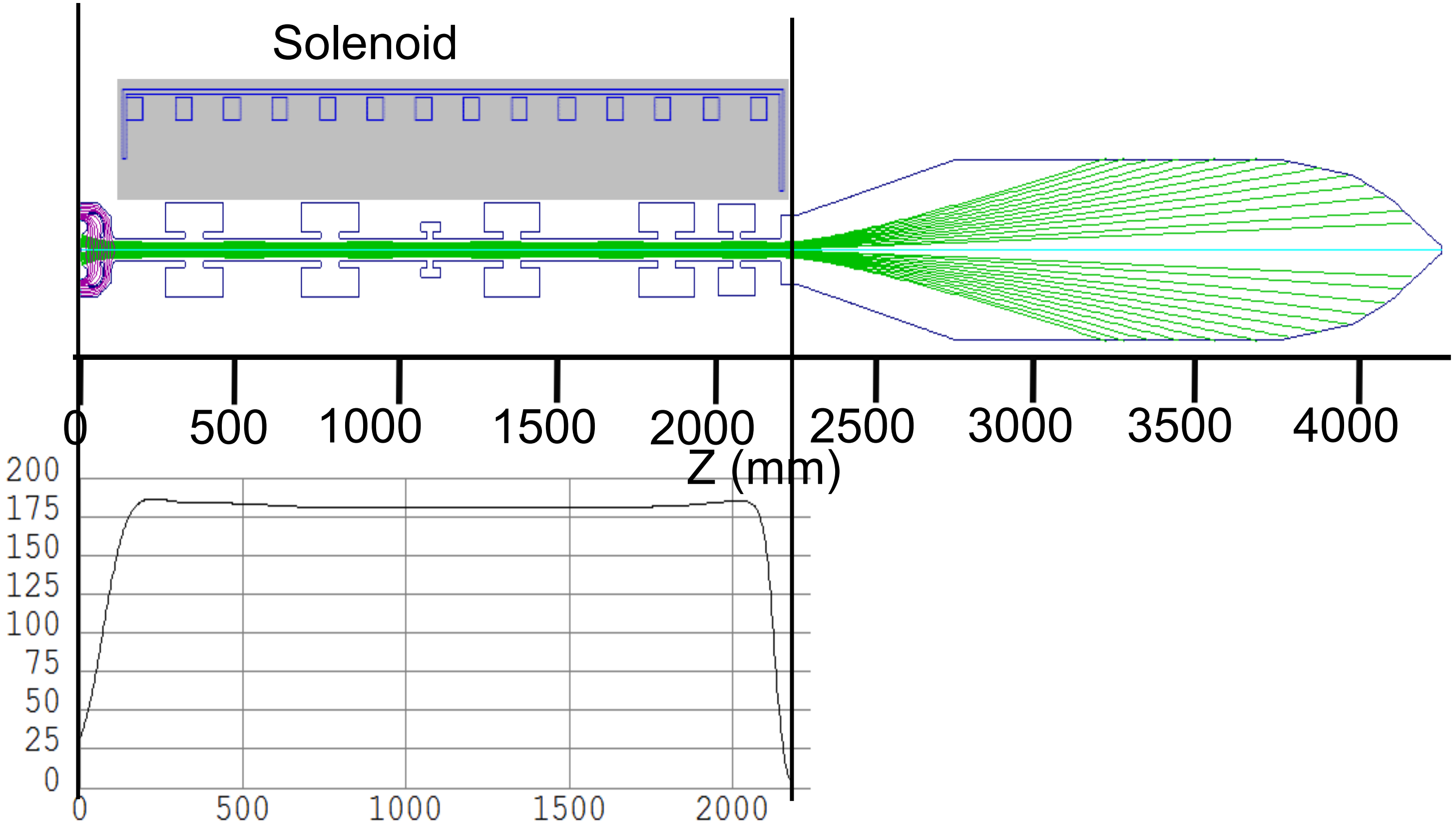
CST

Type	DGUN	EGUN	CST
Current(A)	15.12	14.88	14.88
Beam DIA(mm)	17.8	17.7	17.7
Perveance($\mu A/V^{3/2}$)	1.43	1.41	1.41

Related Key Technologies Development (3)

650MHz High Efficiency Klystron (CW 800kW and efficiency≥75%)

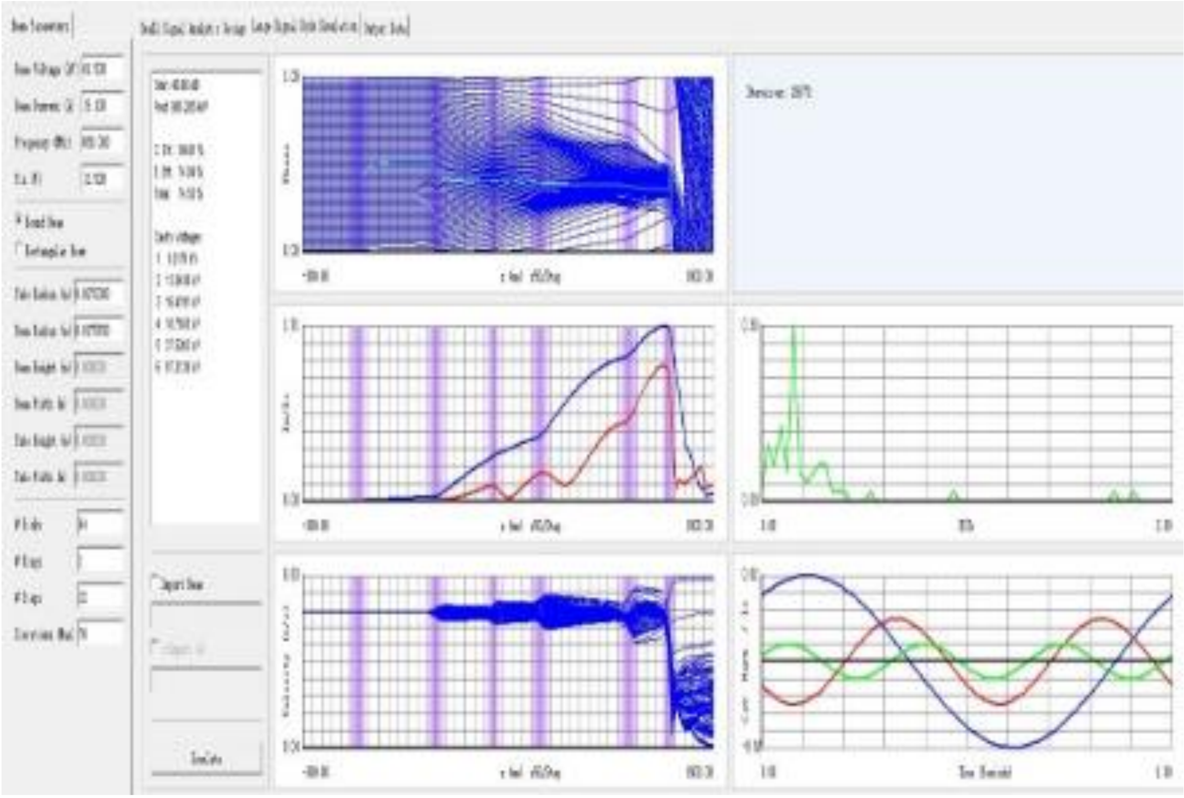
- Prototype 1: Beam trajectory



Related Key Technologies Development (3)

650MHz High Efficiency Klystron (CW 800kW and efficiency≥75%)

- Prototype 1: AJ disk 1d simulation result shows 74.55% efficiency



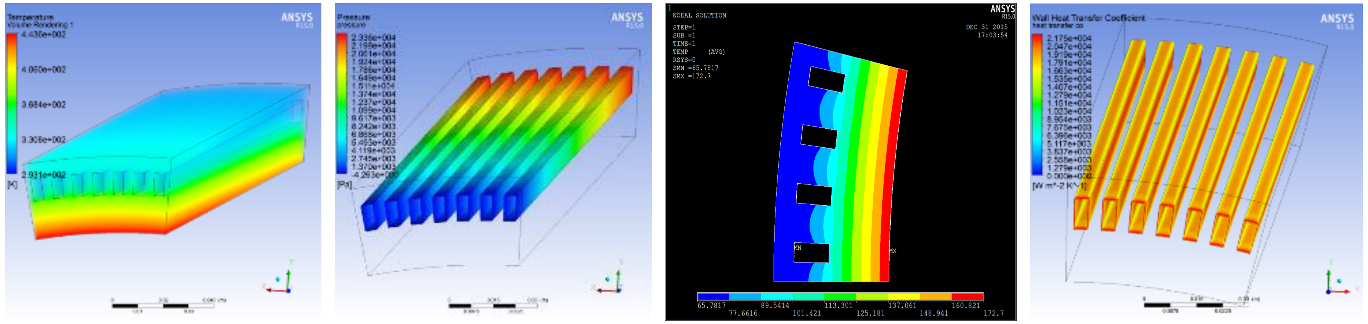
AJ disk design

Related Key Technologies Development (3)

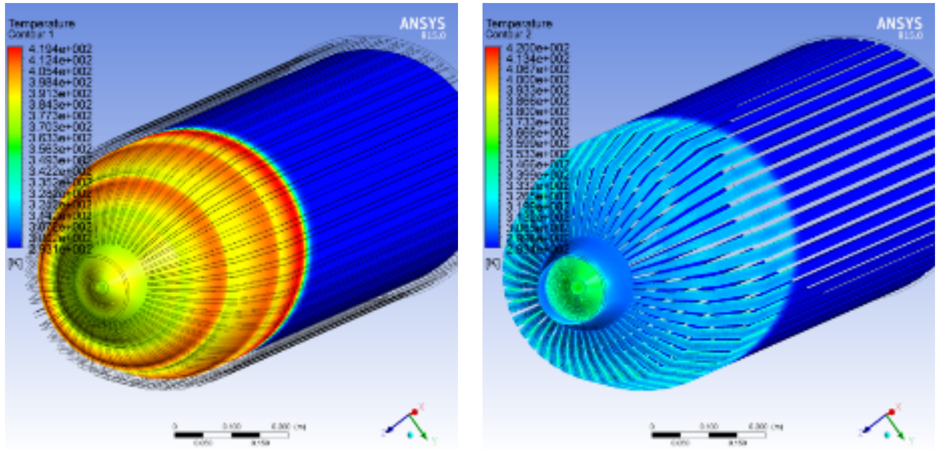
650MHz High Efficiency Klystron (CW 800kW and efficiency≥75%)

- Prototype 1: Full power (~1.23MW) collector design

Groove number	Groove dimensions(a:b)	Total water flow rate	Water pressure loss for smooth surface
180	1:2	1400kg/min	2.34E+4 Pa



Temperature and water pressure loss



Temperature on inner surface of copper domain and water domain

Related Key Technologies Development (4)

PSM (Pulse Step Modulation) Power Supply

- In ADS project, a 80kV/18A PSM power supply was developed for 325MHz 600kW klystron at IHEP
- In PAPS, a 120kV/16A PSM power supply will be developed for 650MHz 800kW klystron

ADS 80kV/18A PSM Power Supply

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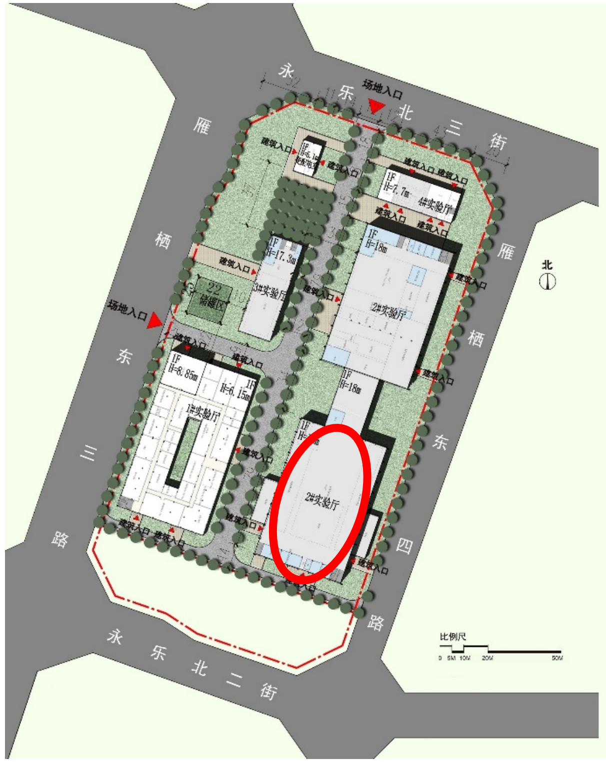
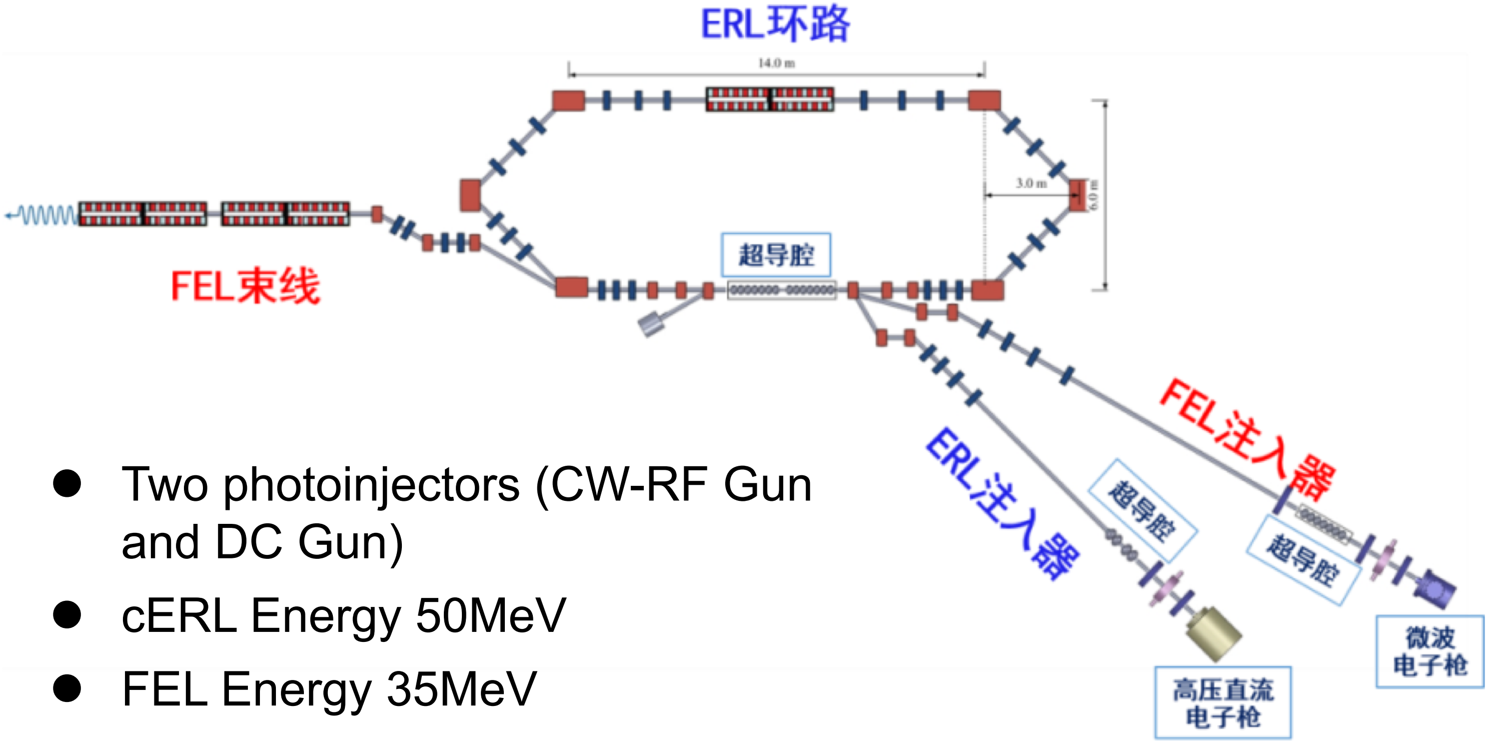
Future Plan

- First, construction and beam operation of beam test system at PAPS (2017.5-2020.6)
- After 2020, the hall for Magnet system will be free up. A compact test facility towards one machine, two purposes: using a common SC linac for XFEL and ERL simultaneously now is proposed at IHEP





- Two photoinjectors (CW-RF Gun and DC Gun)
- cERL Energy 50MeV
- FEL Energy 35MeV

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Summary and Outlook

- A new project PAPS has been supported by Beijing Government from 2017.5-2020.6
- A beam test system based on photocathode DC Gun and 650MHz SRF will be constructed at PAPS
- Several related key technologies already been developed in recent years at IHEP, including photocathode DC Gun, 650MHz SRF cavities, High power high efficiency klystrons and its PSM power supply……

Thank you!